NASA Contractor Report 159147

THE POTENTIAL OF CARBON FIBER INDUCED
SHOCK HAZARDS IN HOUSEHOLD TOASTERS

Jerome A. Meyers

THE BIONETICS CORPORATION
Hampton, Virginia 23666

NASA Contract NAS1-15238
September 1979

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

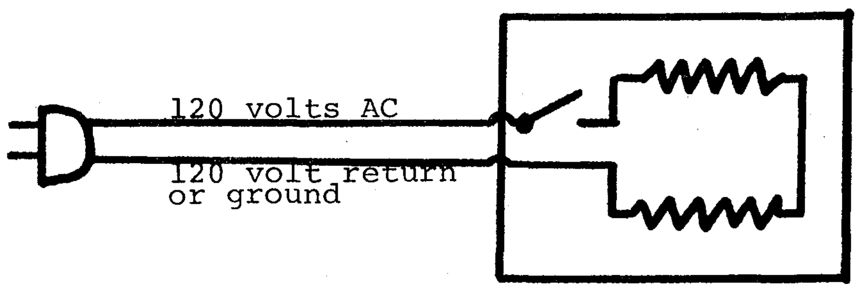
TABLE OF CONTENTS

N80-10434#

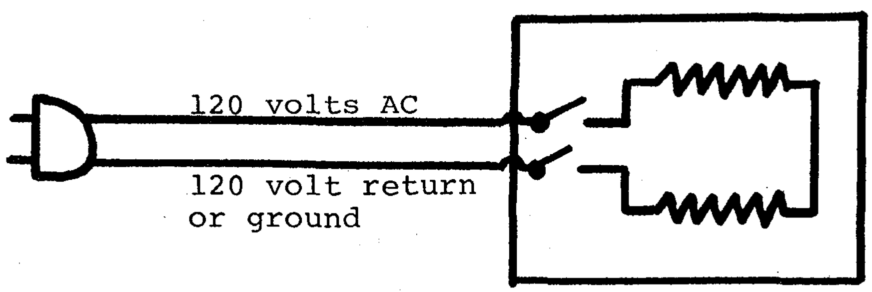
1.0 Introduction

This effort was accomplished under the Graphite Fiber Risk Analysis Program. It is a part of other testing being done on appliances and electrical devices. The objective of this test was to determine the average exposure to carbon fibers which produced a short and potential shock hazard in a household toaster. Toasters are normally in the "OFF" state. They are used for brief periods during the day and have timed cycles during which power is applied. The possibility of a short occurring from the heating element to the case was investigated to find the exposure levels at which a potential shock hazard could appear. The short produced was tested to determine its importance.

Toasters with two types of switching controls are in home use today. Some have a double pole switch and some a single pole switch as shown in the sketches below.



TOASTER WITH A SINGLE POLE SWITCH



TOASTER WITH A DOUBLE POLE SWITCH

It can be seen that if a device with a single pole switch was shorted by a fiber, the case could become hot and be a potential shock hazard with the plug in the wall and with the wall receptacle 110 volt lead connected to the unswitched line of the toaster. Underwriter's Laboratory Standard 499 specified that all toasters manufactured after June 1970 had to have a double pole switch. However, since toasters do not quickly wear out it is estimated that between 10% and 40% of the toasters in use today have the single pole switch.

A short by a fiber, in a toaster with a double pole switch, is possible but there is no inherent hazard in the "OFF" state. Both types of toasters are susceptible to a short from the heating element to the case when power is applied to the device. The current passing thru a person contacting the case would be dependent on the individuals resistance and ground contact.

It should be noted that single fibers of the class used in current aircraft structures will burn out at a current flow of about 10 milliamperes. Attachment 1 shows the effects of current on an average person, and is extracted from Langley Research Center Handbook 1710.6, Electrical Safety Manual Nov. 1975, Chapter 12.

An average airgap distance to create a short from a toaster element to the case is about 7 mm and a fiber of one cm length could cause a short in most areas of the bread slots which are about 13 cm long and 2 cm wide. The expected deposition of fibers into the slots of the toaster can be calculated by using the equation below.

$$P = E\ v\ A$$

Where P = the number of particles in the toaster,

E = Exposure in fiber-seconds/meter^3,

v = Fall velocity in meters/second, and

A = Open area of the toast slots in meters^2.

Exposure	Number of Fibers in Toaster
1×10^4	1
1×10^5	9
1×10^6	90

It can be seen that the probability of a short below an exposure of 10^5 is low, and probably only needs to be considered above this value. The geometry and enclosed areas of a toaster made investigation of post exposure shorts caused by captured fibers necessary. These shorts could be affected by mechanical jostling and equipment heating.

Testing was accomplished to evaluate the redissemination problem and measure the severity of the shock hazard produced by a fiber. This was done by exposing the toasters, with shaking at specific steps, until a short was detected. When the short was seen the toaster was energized to evaluate the hazard produced.

2.0 Method of Testing

Six toasters were selected for testing. Five were devices with a double pole switch. An older toaster with a single pole switch was included to round out the sample. Table 1 gives an estimation of the airgap sizes in the six toasters. The gap length is an estimate of the length of heating element parallel to the case or ground at the specified distance.

The toasters were exposed to 1mm, 3mm, 7mm and 10/12mm fibers of Thornel 300. Table 2 shows lengths, exposure values and number of test runs. Each test was terminated when the toaster exhibited a short or at an exposure of 1×10^8 fiber-seconds/meter^3, whichever came first. With 3mm fibers, testing of toaster 5 was stopped at 1×10^7 as indicated by an asterisk in Table 2. Testing was stopped to conserve time and for other test scheduling constraints. In calculating the average exposure to failure ($\bar{E}$) it was assumed a failure would occur immediately after stopping the test. This added conservatism to the data and only slightly affected the $\bar{E}$.

Toaster 5 was the only device having a single pole switch. The double pole switches of the newer toasters were shorted on one side to enable the detection of 120 volts on the toaster case when a fiber fell from the heating element to the case. Figure 1 is a sketch of the test circuit. The variable resistor was normally set at 25,000 ohms to limit the current to about 5 milliamperes and prevent fiber burnout. The direction of the poles on the plug of the power cord were connected to place the 120 volt line on the unswitched side of the toaster to insure producing a voltage any time a fiber shorted from the toaster case to the heating element.

3.0 Data Analysis

Table 2 shows the exposure which produced the first short in each test run and the average exposure to failure ($\bar{E}$). All averages were calculated as:

$$\frac{\Sigma E}{\text{Number of Test Runs}}$$

Figure 2 shows a plot of the average exposures of the six toasters displaying a shock hazard versus fiber length. The curve is the numerical average of the points at each fiber length and should represent a good estimation of the exposure at which most toasters should exhibit a short. The exposure values at a specific fiber length fall within an order of magnitude and the differences are believed to be a result of the geometry of construction and the airgap sizes.

A shock hazard should be impossible to produce in a double pole switched toaster except while it is activated and has power applied. To determine the severity of the short and the effect of movement on redissemination, further testing was done using 3mm long fibers. The toasters were exposed to 1×10^5 fiber-seconds/meter^3. They were jostled by manually moving them four inches forward and back and then side to side. If no short occurred, exposure was increased in steps of $\sqrt{10}$ to 3×10^5, 1×10^6, 3×10^6, 1×10^7 and 3×10^7 until a short was seen on the test instrumentation. The results of five test runs are shown in Table 3. An average value for $\bar{E}$ jostle is shown with an $\bar{E}$ from Table 2 (static) shown in the next column for comparison. It can be seen that jostling or redissemination due to movement did not have a significant effect on the average exposure to failure.

Since the enclosed area of the toaster may retain fibers, the question, "Once a shock hazard appears will the toaster present a hazard forever?" may be asked. Testing to answer this specific question was not undertaken but the probability of a hazard must be greatest immediately after exposure. It was found that a fiber will

not burn or oxidize when placed on a hot toaster element, but the fibers will be removed when the toaster is cleaned. They will be blown out by convection currents when the toaster is used and will be covered by bread crumbs and other debris decreasing their ability to cause a short. Thus, the probability of the shock hazard will decrease after exposure and if one does occur it will be no more severe than the minor hazard described in the following paragraphs.

To show the cumulative failure versus the exposure the data in Table 2 was plotted in Figures 3 through 8. The left most curve in Figure 4 is a plot of $y = 1-e^{-E/\overline{E}}$ used as a comparison. If the slope of the experimental curve is appreciably more steep a multi-fiber produced short is indicated. Toaster failures may require a threshold level of fibers and subsequent additions combine with those inside to produce high failure rates versus exposure. The steep slope represents a quickly produced failure once the threshold accumulation is reached. Conversely, a slope parallel to the reference curve indicates a single fiber short since at low exposure levels the failure probability will be linearly related to the number of injested fibers.

Examining the figures by comparison with the standard curve in Figure 3 leads to the following observations. Figure 3, 4, and 5 agree well with the exponential curve and probably represent single fiber events. Figures 6 and 7 indicate single fiber events with longer fibers that can bridge a wider gap while the steepness of the 3mm curves and the larger exposure to failure indicate a multi-fiber induced short. The 3mm curve in Figure 7 shows only five points because an actual failure was not observed in the other five tests since exposure was stopped at 1×10^7 fiber-seconds/meter^3.

It is believed this curve would be steep if further failure data was available. Figure 8 shows strong multi-fiber produced events at 7mm. The 3mm curve should be expected to be steep. The shallowness may be due to statistical problems with the small sampling or to a construction peculiarity. This toaster had some airgaps that could be bridged by a 3mm fiber. It was the only toaster that had a reasonable amount of very short airgaps as shown in Table 1.

To test the severity of the shock hazard the voltage on the case was measured. Since a toaster's main circuit is a resistor with one side at 110 volts and the other at ground, the voltage on the case should vary from 110 volts to zero depending upon where the fiber hits the resistive element. Therefore half of the shorts will produce an insignificant current since the potential would be 55 volts or less. For test purposes, one side of the double pole switch was shorted to enable 110 volts to be shorted to the heating element at any time. When a short was detected an attempt was made to measure the current flowing to ground when the resistance was reduced on the potentiometer. Knowing the current would enable calculation of the resistance and by using the data in Figure 9 , the severity of the hazard would be estimated. In 25 instances of producing a short shown in Table 3, the hazard lasted long enough to measure a current only three times. The resistance shown in Table 3 and the current is the last value obtainable. Burnout of the fiber happended immediately after the measurement was taken.

The reason for the brief duration of the hazard was investigated. Measuring the velocity of the air flow above the toaster caused by heating gave an average value of 60 feet per minute. A

fiber falls at a rate of about five feet per minute. Thus, unless the fiber was firmly lodged convection currents from the heating element are strong enough to displace the short. This happened about 88% of the times that power was applied to the toaster. On one occassion a clump of about 30 fibers was seen rising from the toaster on activating the heating switch. This demonstrated the lifting power of the heat currents. Further, a fiber burns out upon carrying a current of about 10 ma. At 110 volts this would require a resistance of 10 k ohms or less. According to Figure 9 , this current could produce a "no let go" situation if an individual was grounded and had a firm grip on the toaster. If a human could supply a low enough resistance path to ground the fiber could not carry enough current, before burning out, to be fatal. Attachment 2 shows a current of 10 ma to be painful and possibly cause paralysis. The duration of the shock hazard must be brief when we consider convection currents, movement of the toaster dislodging shorts, and fiber burnout.

4.0 Conclusions

Cumulative failure curves indicate shorts are predominantly single fiber events with good agreement to an exponential curve. Multifiber shorts are mainly seen at shorter fiber lengths.

Toasters are a minor shock hazard since a large exposure is required to produce a short, a Thornel 300 fiber will burn out if 10 ma or more flow through it, most fibers get displaced by convection currents and double pole toasters cannot be shorted except while they are on, and they are off most of the time.

Work under way by other investigators indicates in addition that longer length fibers are not released in quantity from a fire

and the fibers may have smaller diameters, higher resistance and lower burn out currents.

Single pole switch toasters may be shorted any time the plug is placed in the wall with the unswitched wire connected to the 120 volt line. This may happen 50% of the time. If the toaster is plugged in with the switched side connected to the 120 volt return a shock will be possible only when the toaster is energized. This type of toaster is expected to be rare by the time significant carbon fibers are used in aircraft structures since none were manufactured after 1970.

Data show jostling does not significantly effect the average exposure to produce a shock hazard in a toaster. It is as apt to break a short as initiate one.

Experimentation indicates a shock hazard in a toaster will be of short duration. With the Thornel 300 fibers tested the most serious effect would be momentary pain and possibly the onset of arm paralysis if the short persists.

CURRENT RANGE AND EFFECT ON AN AVERAGE MAN

Current	Physiological Phenomena	Feeling or Lethal Incidence
>1 mA	None	Imperceptible
1 mA	Perception threshold	
1-3 mA		Mild sensation
3-10 mA		Painful sensation
10 mA	Paralysis threshold of arms	Cannot release hand grip. If no grip, victim may be thrown clear. (May progress to higher current and be fatal.)
30 mA	Respiratory paralysis	Stoppage of breathing. (Frequently fatal)
75 mA	Fibrillation threshold 0.5 percent	Heart action discoordinated. (Probably fatal.)
250 mA	Fibrillation threshold 99.5 percent (≫ 5-s exposure)	
4 A	Heart paralysis threshold (no fibrillation)	Heart stops during current passage, restarts normally on current interruption. (Usually not fatal from heart disfunction.)
5 A	Tissue burning	Not fatal unless vital organs are burned

Extracted from Electrical Safety Manual, 1710.6, November, 1975, Chapter 12.

ATTACHMENT 1

TYPE TOASTER	ESTIMATED GAP LENGTH	AIRGAP SIZE
Toaster 1	52 CM	13 MM
2 Slice	8 CM	7 MM
Toaster 2	20 CM	8 MM
4 Slice	100 CM	9 MM
Toaster 3	36 CM	9 MM
2 Slice	20 CM	16 MM
Toaster 4	81 CM	12 MM
4 Slice	20 CM	13 MM
	25 CM	8 MM
Toaster 5	180 CM	10 MM
2 Slice	60 CM	15 MM
Toaster 6	5 CM	2 MM
2 Slice	5 CM	4 MM
	60 CM	5 MM
	150 CM	6 MM

TABLE 1

EXPOSURES TO PRODUCE A SHORT IN SIX TOASTERS

			TEST RUN NUMBER									
TOASTER	L.	$\overline{E}$ AVERAGE	1	2	3	4	5	6	7	8	9	10
Toaster 1	1MM	No Fail	1.06x8									
2 Slice	3MM	8.28x10^6	2.67x7	1.04x7	1.89x7	3.40x7	8.28x6					
	7MM	1.64x10^6	4.02x6	2.91x5	2.17x6	8.55x5	8.66x5					
	10MM	1.01x10^6	5.90x5	1.84x5	1.43x6	6.54x5	2.19x6					
Toaster 2	1	No Fail	1.00x8									
4 Slice	3	4.68x10^7	7.21x7	6.61x7	3.56x7	3.99x7	2.03x7					
	7	1.27x10^6	1.09x6	2.00x6	6.76x5	2.05x6	5.50x5					
	10	6.15x10^5	2.79x5	4.72x5	1.11x6	7.74x5	4.38x5					
Toaster 3	1	No Fail	1.06x8									
2 Slice	3	3.04x10^7	6.55x7	3.37x6	2.78x7	4.31x6	5.11x7					
	7	1.44x10^6	1.81x6	2.16x5	3.33x5	2.54x6	2.32x6					
	10	6.13x10^5	9.15x5	9.08x5	3.96x5	2.39x5	6.09x5					
Toaster 4	1	No Fail	1.06x8									
4 Slice	3	5.34x10^6	1.07x7	3.97x6	4.26x6	4.75x6	3.03x6					
	7	7.51x10^5	2.97x5	4.75x5	1.89x6	6.28x5	4.66x5					
	10	3.46x10^5	8.97x5	4.17x5	7.82x4	1.32x5	2.07x5					
Toaster 5	1	No Fail	1.21x8									
2 Slice	3	1.00x10^7	5.58x6*	1.08x7*	1.13x7*	1.09x7*	9.98x6	1.21x7	1.12x7*	1.12x7	1.13x7	5.84x6
	7	2.68x10^6	5.85x5	8.24x4	1.59x6	1.72x6	8.93x5	3.98x6	4.19x6	9.16x6	2.40x6	2.23x6
	12	2.05x10^6	2.10x6	2.52x6	5.04x6	5.12x6	3.19x5	2.10x6	1.47x6	5.46x5	3.67x5	8.72x5
Toaster 6	1	8.21x10^7	2.95x7	6.32x7	2.80x7	1.00x8*	1.00x8*	1.00x8*	1.00x8*	1.00x8*	1.00x8*	1.00x8*
2 Slice	3	3.35x10^6	6.22x5	4.29x6	1.13x7	4.62x6	2.73x6	7.08x6	4.20x5	1.26x6	1.16x6	5.25x4
	7	1.02x10^6	1.42x6	1.00x6	9.07x5	9.05x5	8.93x5	8.79x5	9.21x5	9.89x5	5.73x5	1.76x6
	12	2.14x10^5	2.31x4	1.26x4	9.45x5	2.10x4	3.17x5	4.83x4	1.19x5	7.77x4	2.10x5	3.67x5

*NO HAZARD ON THIS RUN

TABLE 2

Type Toaster	Exposure at which Short Occurred	Short During Exposure or Jostle	$\bar{E}$ Jostle	$\bar{E}$ Static	Voltage On Case After Applying Power	Duration of Short After Applying Power	Current and Resistance to Ground at Fiber Burnout I	R
Toaster 1 2 Slice	1.00×10^7	Jostle	1.59×10^7	8.28×10^6	30V	< 20 Sec	Unable	Unable
	2.04×10^7	Exposure			76V	< 20 Sec	Unable	Unable
	8.59×10^6	Exposure			54V	< 20 Sec	Unable	Unable
	1.00×10^7	Jostle			79V	< 20 Sec	Unable	Unable
	3.04×10^7	Jostle			79V		7 MA	10.2 K
Toaster 3 2 Slice	9.31×10^6	Exposure	2.11×10^7	3.04×10^7	108V	< 10 Sec	Unable	Unable
	2.32×10^7	Exposure			23V	< 10 Sec	Unable	Unable
	1.39×10^7	Exposure			51V	< 10 Sec	Unable	Unable
	1.97×10^7	Exposure			58V	< 10 Sec	Unable	Unable
	3.96×10^7	Exposure			74.3V	< 10 Sec	Unable	Unable
Toaster 4 4 Slice	2.73×10^6	Exposure	3.05×10^6	5.34×10^6	110V	< 10 Sec	Unable	Unable
	4.68×10^5	Exposure			104V		9.4 MA	11 K
	8.03×10^6	Exposure			49.2V		9.1 MA	5.4 K
	3.02×10^6	Jostle			93.4V	< 20 Sec	Unable	Unable
	1.01×10^6	Jostle			Unable	< 10 Sec	Unable	Unable

TABLE 3

TESTING WITH 3MM FIBERS TO DETERMINE SIGNIFICANCE OF SHORTS

Type Toaster	Exposure at which Short Occurred	Short During Exposure or Jostle	$\bar{E}$ Jostle	$\bar{E}$ No Jostle	Voltage On Case After Applying Power	Duration of Short After Applying Power	Current and Resistance to Ground at Fiber Burnout I	R
Toaster 5 2 Slice	9.31×10^{6}	Exposure	2.57×10^{7}	1.00×10^{7}	97V	< 10 Sec	Unable	Unable
	5.74×10^{7}	Exposure			109V	< 10 Sec	Unable	Unable
	1.41×10^{7}	Exposure			86V	< 10 Sec	Unable	Unable
	1.28×10^{7}	Exposure			64V	< 10 Sec	Unable	Unable
	3.48×10^{7}	Exposure			46V	< 10 Sec	Unable	Unable
Toaster 6 2 Slice	1.00×10^{5}	Jostle	6.54×10^{6}	3.35×10^{6}	40V	< 20 Sec	Unable	Unable
	2.04×10^{7}	Jostle			Unable	< 10 Sec	Unable	Unable
	8.90×10^{6}	Exposure			25V	< 20 Sec	Unable	Unable
	3.02×10^{6}	Jostle			78V	< 20 Sec	Unable	Unable
	3.00×10^{5}	Jostle			88V	< 20 Sec	Unable	Unable

TABLE 3
(Cont)

TESTING WITH 3mm FIBERS TO DETERMINE SIGNIFICANCE OF SHORTS

TEST CIRCUIT

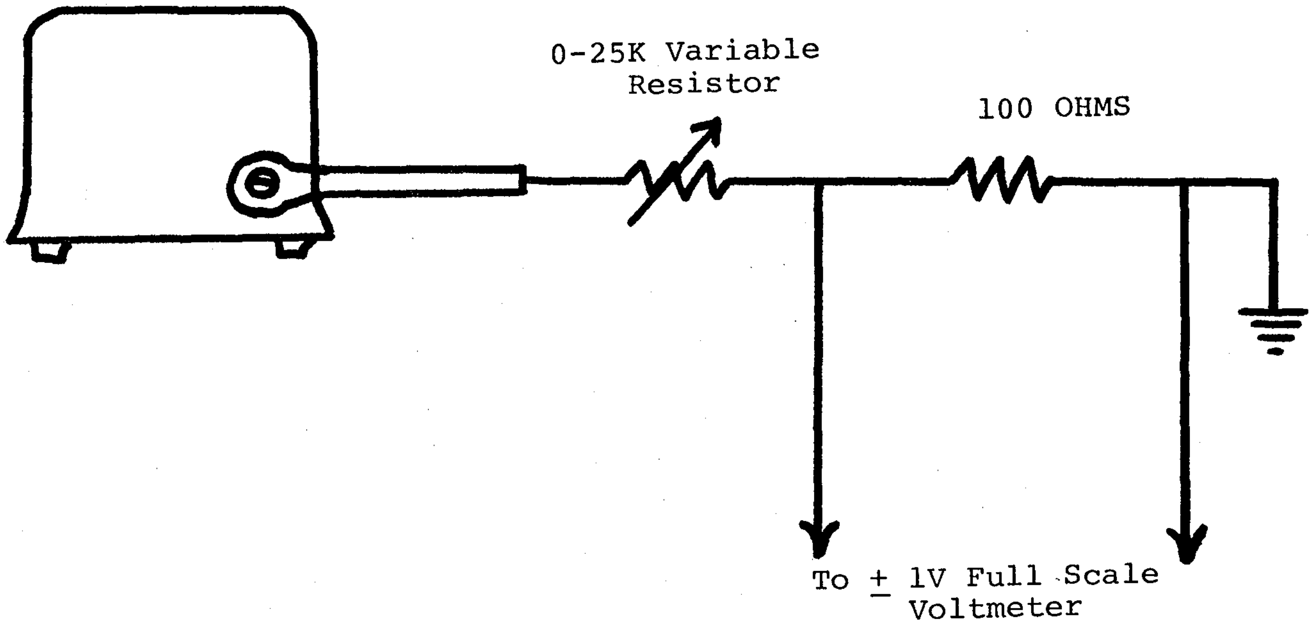


FIGURE 1

AVERAGE EXPOSURE OF SHORT
TO CASE OF SIX TOASTERS TESTED AT
LENGTHS OF 1, 3, 7 and 10-12 MM.

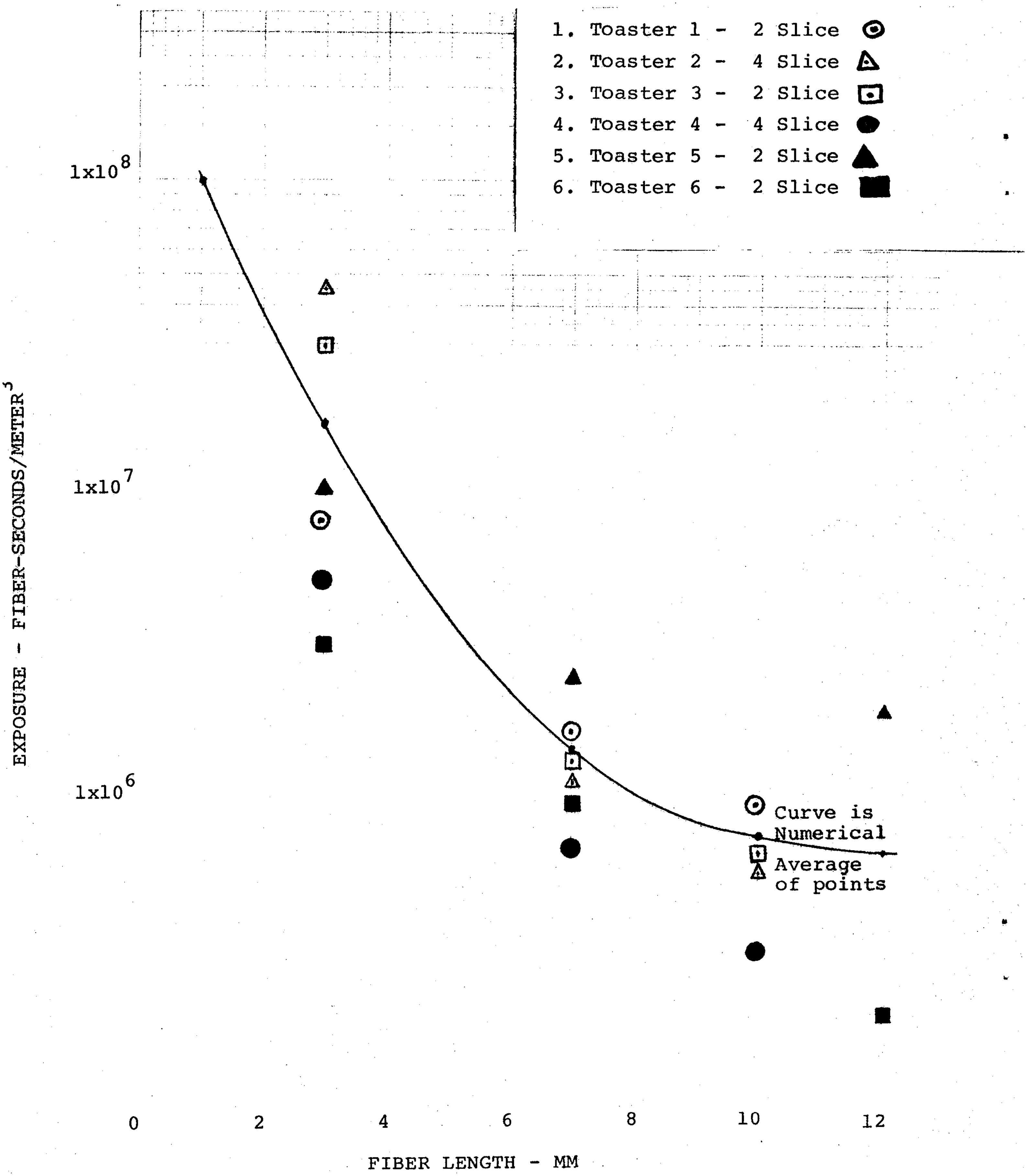


FIGURE 2

FIGURE 3

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 1 - 2 SLICE

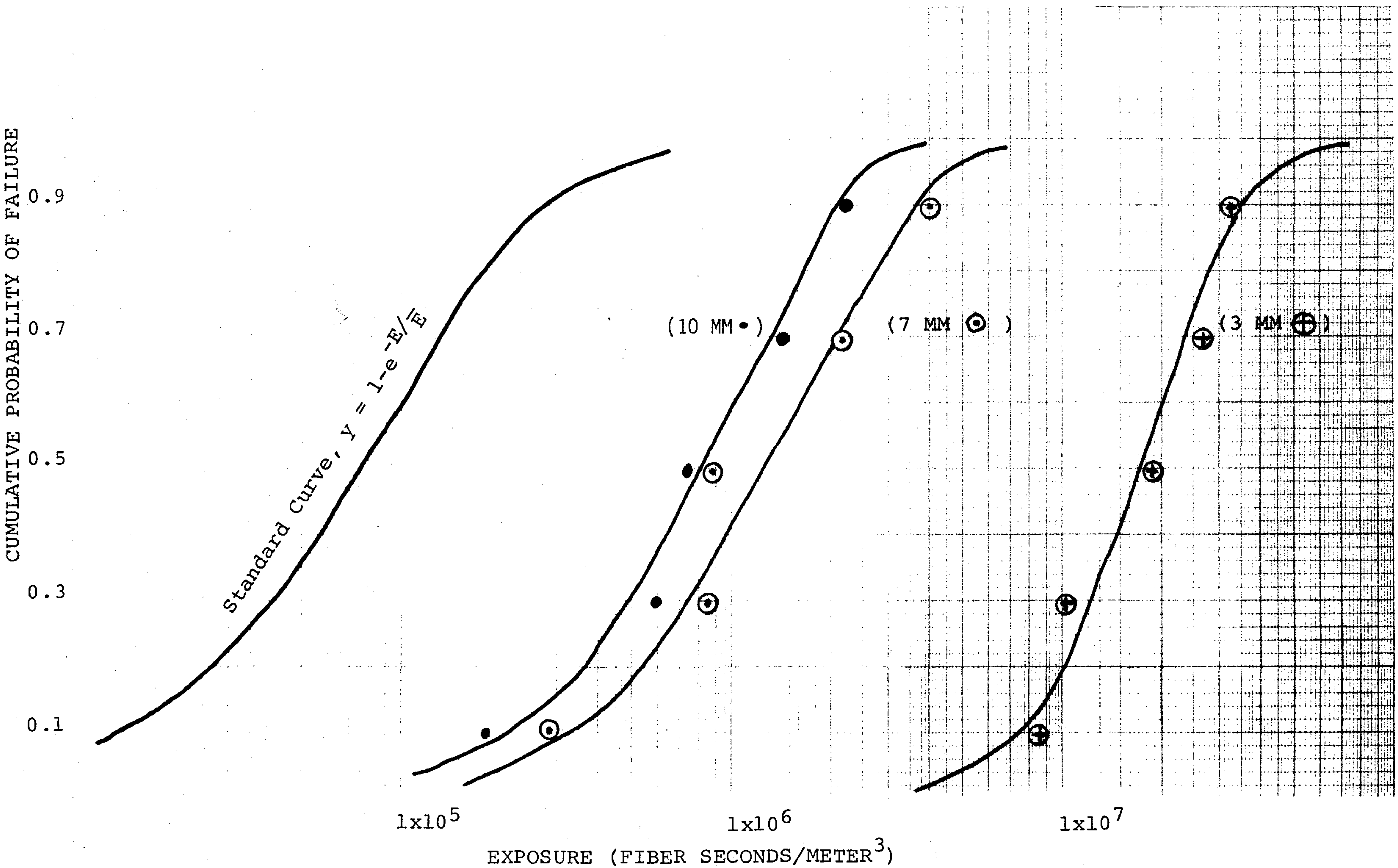


FIGURE 4

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 2 - 4 SLICE

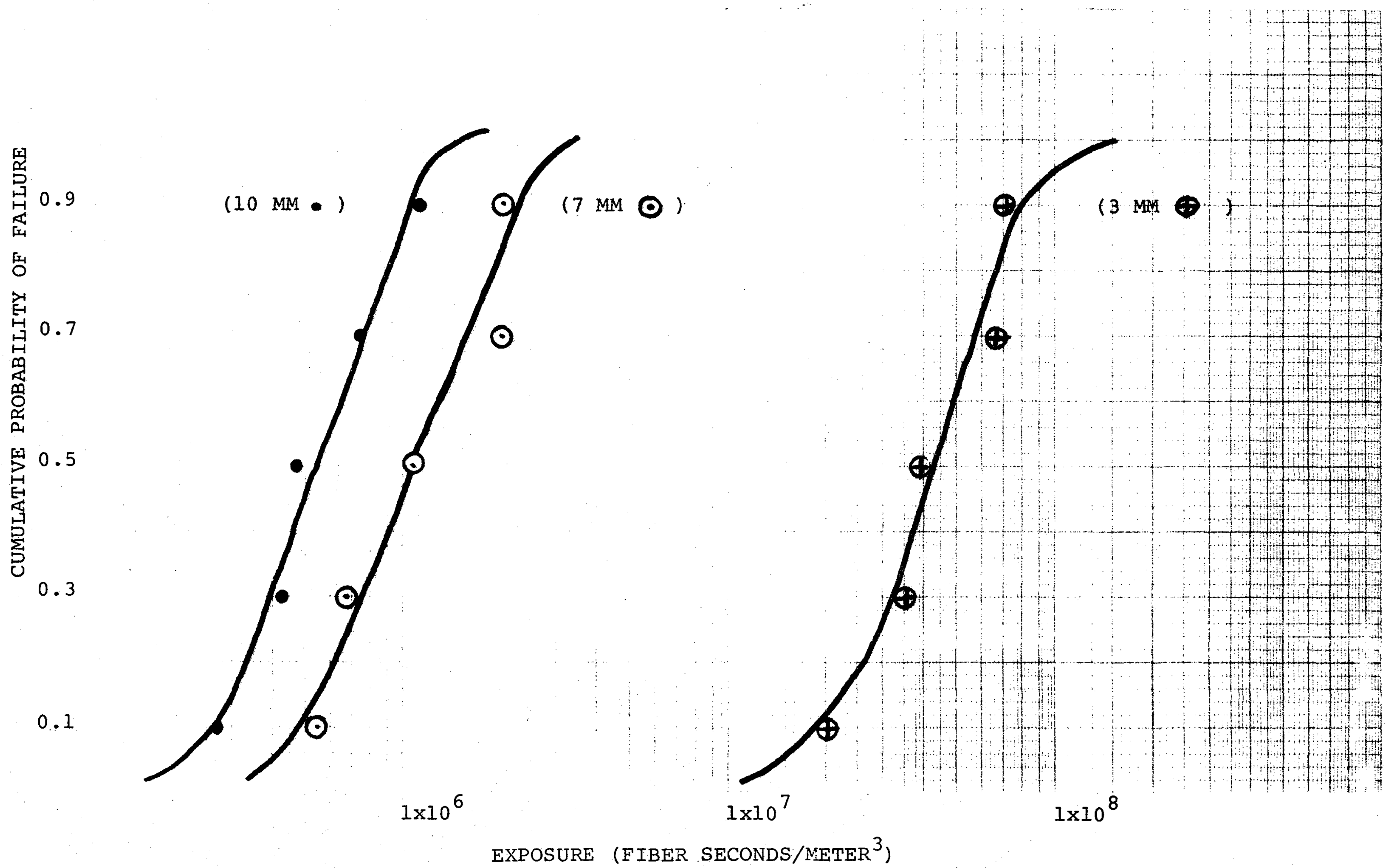


FIGURE 5

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 3 - 2 SLICE

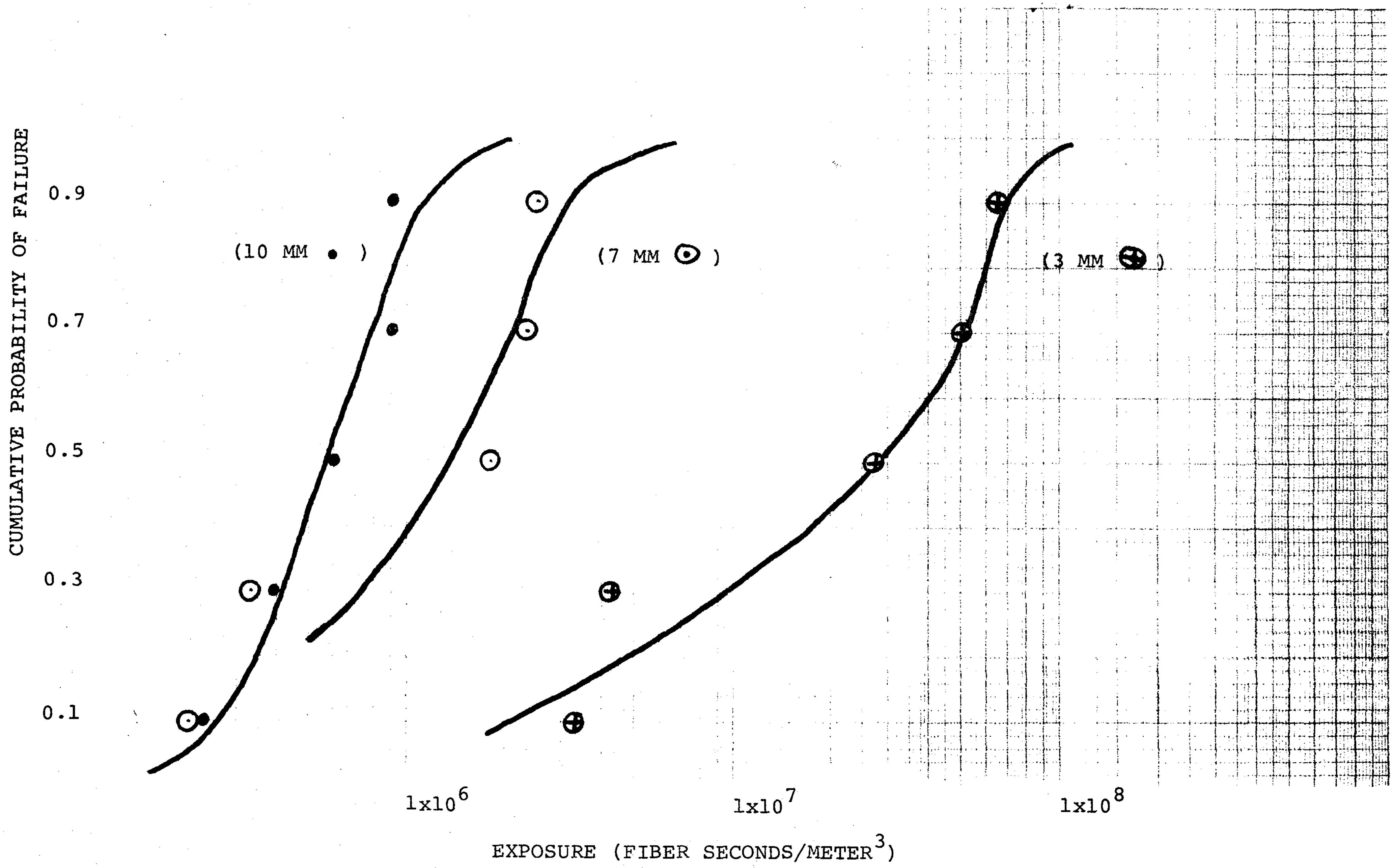


FIGURE 6

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 4 - 4 SLICE

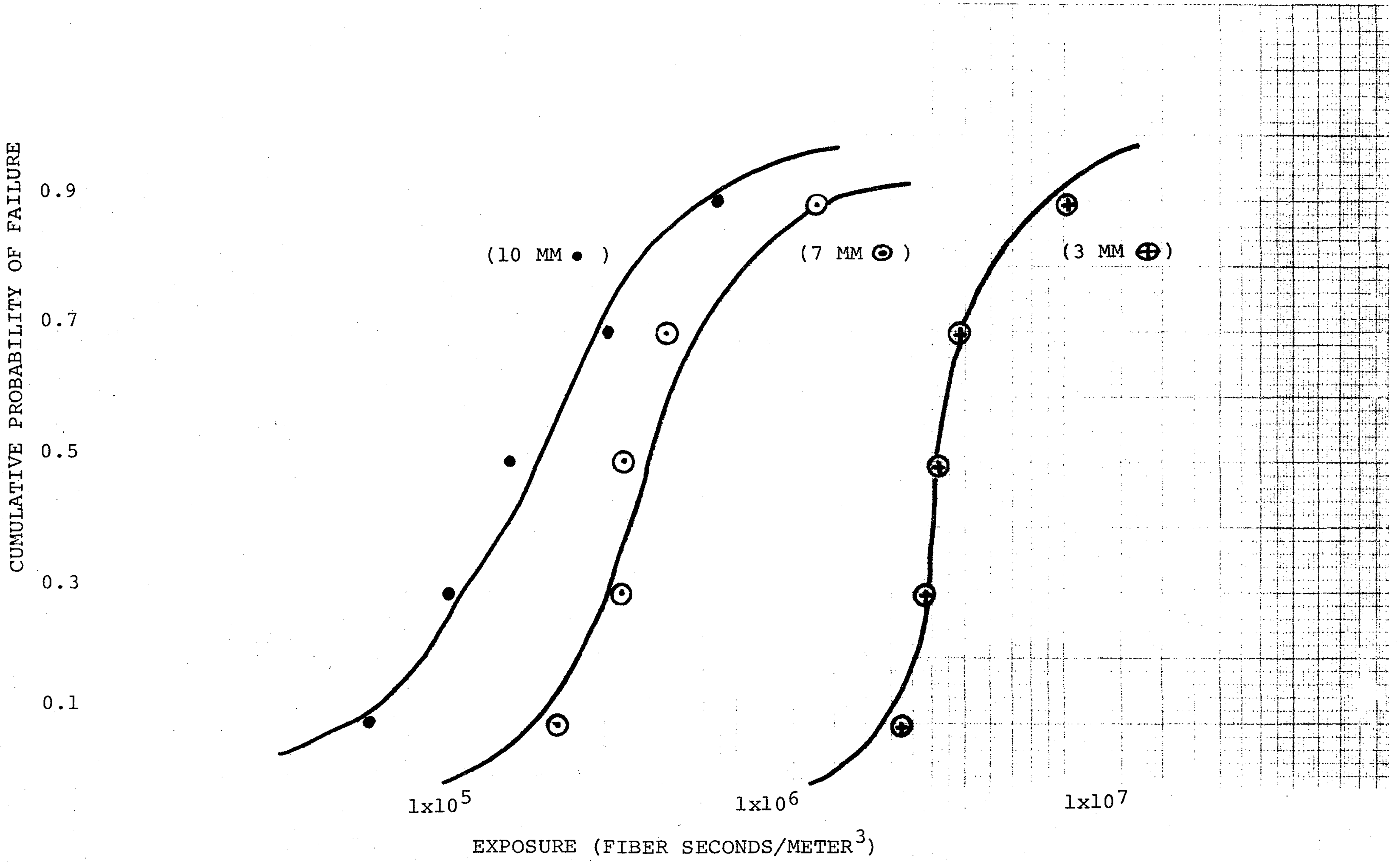


FIGURE 7

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 5 - 2 SLICE

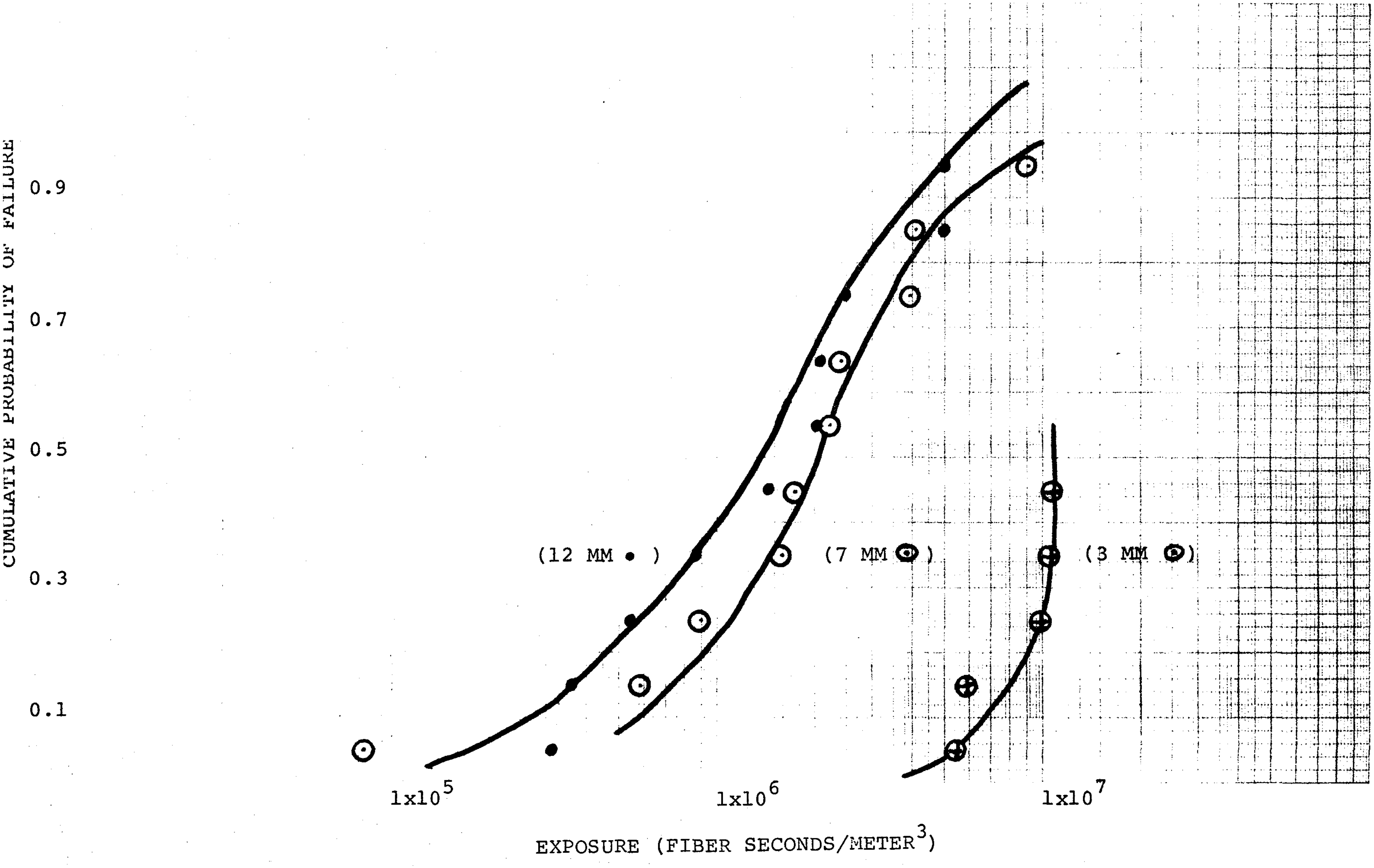
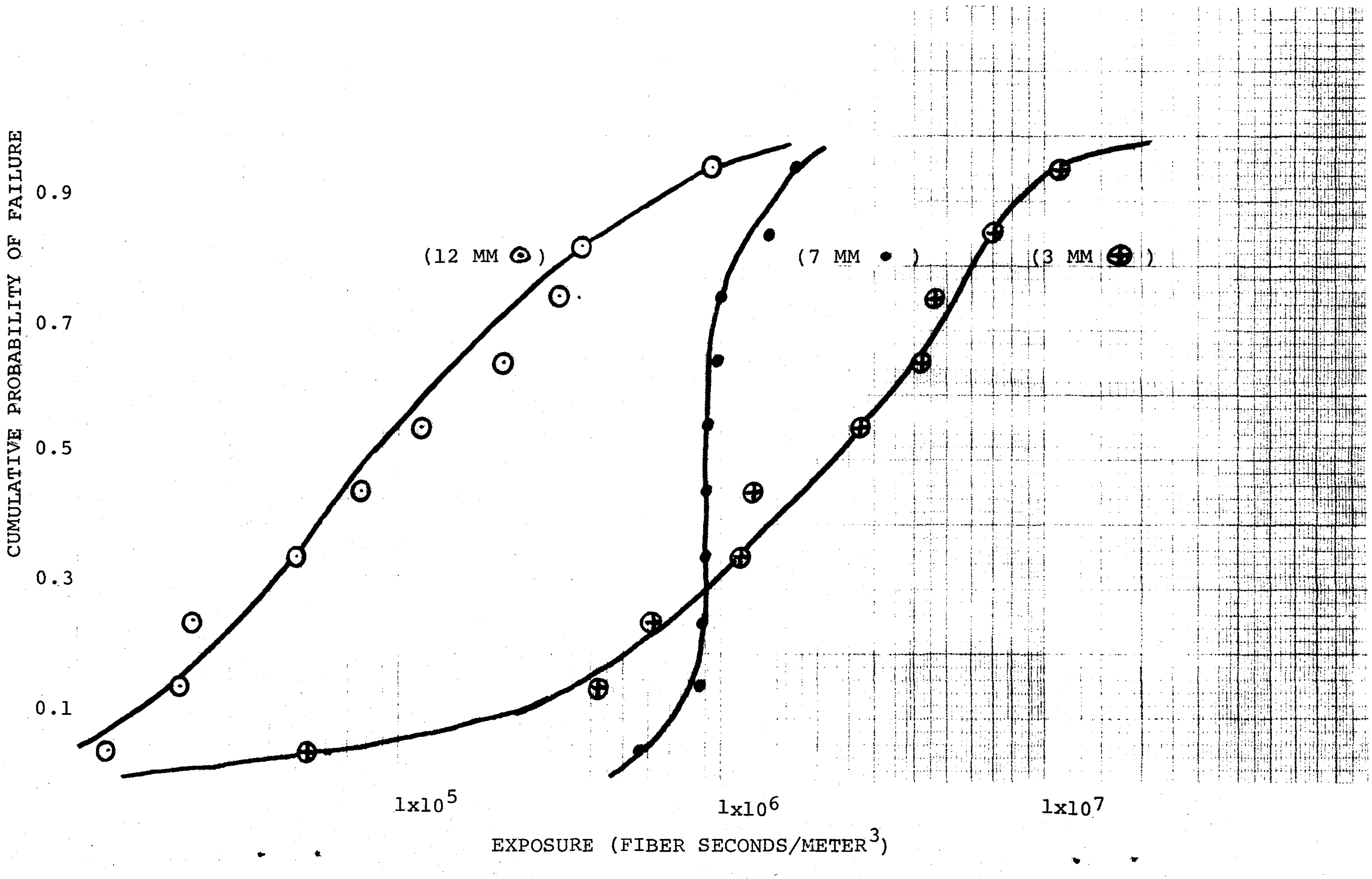


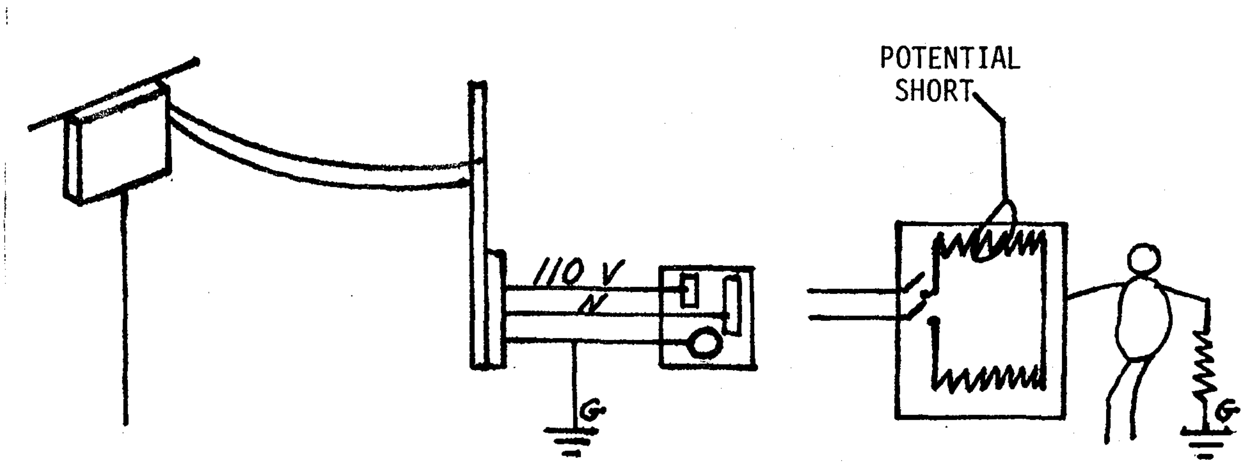
FIGURE 8

CUMULATIVE FAILURE VERSUS EXPOSURE

TOASTER 6 - 2 SLICE



POTENTIAL SHOCK HAZARD



CONTACT	RE: OHMS	CURRENT AMP	EFFECT
DRY, TOUCH CASE	MEGOHMS	-	NONE
DRY, FINGER-THUMB GRASP	30 K	.003	MILD
WET, FINGER TOUCH	20 K	.005	ANNOYANCE
DRY, HAND HOLDING PLIER	10 K	.009	"NO-LET-GO"
DRY, PALM TOUCH	3 K	.030	VENTRICULAR FIBRILLATION
FOOT, ON DAMP LEATHER	12 K	.009	"NO-LET-GO"
FOOT, ON WET CONCRETE	1 K	.110	FIBER BURNS OUT

FIGURE 9